

# A Frequency and Timing Subsystem for the ORION Mobile Unit

P. A. Clements

Communications Systems Research Section

*JPL is building a mobile surveying instrument in support of the NASA crustal dynamics program. This instrument will measure the length and direction of the distance between sites on the Earth's surface. This is done using Very Long Baseline Interferometry techniques operating at microwave frequencies using extragalactic radio sources (QUASARS). One of the subsystems is the Frequency and Timing Subsystem. The frequency standard used is a hydrogen maser, which is the most stable operational frequency standard in the world today. It is also a device which is sensitive to its environment, so great care must be taken in installation and operation. An important part of the subsystem is a sophisticated automatic system to monitor frequency stability and accumulated clock error.*

## I. Introduction

A special-purpose Frequency and Timing Subsystem (FTS) is needed for the Operational Radio Interferometry Observation Network (ORION) Mobile Station, (Ref. 1) which is being designed and built by JPL. The ORION mobile station is a part of the ORION System. This system employs Very Long Baseline Interferometry (VLBI) techniques to create a surveying instrument capable of determining the length and direction between two points on the Earth's surface to a precision of 5 centimeters over a distance of up to 5000 kilometers.

## II. Functional Requirements Imposed on the FTS

The Functional Requirement Document (FRD) for the ORION mobile unit includes the following requirements on the FTS:

Frequency performance:

- (1) Stability of  $1 \times 10^{-14} \Delta f/f$  for averaging time of >60 seconds.
- (2) Isolation of >60 dB between ports
- (3) Output level of 13 dBm  $\pm 3$  dB in 50 ohms

Frequency distribution: There are four output ports required for the other subsystems in the ORION mobile unit. The Phase Calibrator Subsystem (PCS), one port, and the Data Acquisition Subsystem (DAS) three ports. Both of these other subsystems require 5 MHz. The FTS will provide ports at the FTS cabinet which will supply these frequencies. System cables will interconnect these ports to the other subsystems.

Epoch time: The time of year to the second will be available (day, hour, minute, and second). This time is needed so it can be entered into the computer when it is turned on, which

occurs when the ORION mobile unit is put into the operational mode.

**Timing pulse distribution:** There is one output port required for the DAS. This timing pulse will establish time of second to within 1 microsec. It is not required that the pulse be exactly on the second, but that the offset be known to within 1 microsec with respect to the United States Naval Observatory (USNO). The FTS will supply this port at the FTS cabinet. A system cable will interconnect it to the DAS. This timing pulse will be 1 pulse per sec (PPS), at least 4 V peak into 50 ohms.

**Performance monitoring:** Certain parameters will be measured to ascertain that the FTS is operating as required, such information will be provided to the unit computer through RS232C interfaces.

**Power:**

- (1) Certain parts of the FTS will need to operate continuously. Therefore dc power must be provided during transit of the ORION mobile unit. The allowable FTS budget is 300 W.
- (2) The portion of the FTS that runs on ac power will use 105-130 Vac, 1 phase, 48-63 Hz at less than 890 W.

The FTS will be usable and meet all specifications in less than four hours after arrival at an operational site.

### III. Satisfaction of the Requirements

All of the functional requirements can be met. However, a hydrogen maser is a delicate instrument that requires special attention. The best results are obtained in a laboratory environment with everything kept in proper adjustment. Even with the most sophisticated environmental controls and careful operational procedures, it is difficult to obtain laboratory performance in a mobile van.

Establishing epoch time synchronized with USNO to less than 1 microsec is a nontrivial task. Present methods require the use of a traveling atomic cesium clock with several calibrations per year. This is combined with careful record keeping to give time synchronization to the sub-microsec level. The new satellite systems (Transit, Nova and Navstar) offer promise of a partially automatic timekeeping capability between the 10 to 1 microsec level, depending on the system utilized.

### IV. Description of the FTS

#### A. The Basic Subsystem

To meet these requirements an FTS design was proposed. The basic part of the FTS consists of a hydrogen maser frequency standard, a distribution amplifier, and a clock

(Fig. 1). These three devices are powered continuously using the mobile unit's dc or ac power, which allows the FTS to provide the performance to specifications within four hours after arrival on site. (There is the withstanding mode during which no power is available and all equipment is to be shut down. This is discussed later in this paper.)

**1. The frequency standard.** The primary source of a stable frequency for the FTS is a hydrogen maser frequency standard (Refs. 2-4). The hydrogen maser is the most stable operational frequency standard in the world today (for averaging times of  $>1$  sec). It is the only frequency standard available that can possibly meet the ORION system frequency stability requirements. Like all frequency standards the hydrogen maser is susceptible to vibration, changes in temperature, magnetic fields and barometric pressure. The superior stability of the hydrogen maser makes these influences very apparent, so great care must be taken any time a hydrogen maser is installed in a system.

**2. The distribution amplifier.** The distribution amplifier has a 5-MHz input signal from the hydrogen maser. Its output consists of several 5-MHz signals which are all coherent with the input. The isolation between any two output ports is 60 dB minimum. Furthermore, the amplifier must not degrade the hydrogen maser stability. All of the levels at the four output ports will be 13 dBm  $\pm 3$  dB into a 50-ohm termination. (An amplifier with these capabilities is not readily available.) Presently there are four candidates — two commercial and two noncommercial. A tradeoff study will be made during the first quarter of 1981. All of these amplifier types will be tested on a HP5390A frequency stability analyzer. The selection will be based on technical performance and cost.

**3. The clock.** The third part of the basic system is the clock. There are other clocks in the FTS (described later in this document) but this is the primary clock and will be known as the FTS clock. The FTS clock has one 5-MHz input from the distribution amplifier and hydrogen maser. It has two outputs: (1) the time of year and (2) four 1-PPS ports. These 1-PPS outputs have time of second information to the nearest microsec. The time of year to the second is available to the computer through a RS232C interface. One of the functions of the FTS clock is to provide a knowledge of time with respect to USNO within 1 microsec. The stability and offset of that signal will determine the accumulated clock error. With a hydrogen maser the maximum accumulated clock error should be approximately 1 microsec per month (which is  $\Delta T/T \approx 4 \times 10^{-13}$ ).

#### B. Time and Frequency Comparison

In order to meet the requirement to monitor the FTS and to have knowledge of the FTS clock time to 1 microsec with

respect to USNO, additional components are needed in the FTS. These components form two systems; one is the time comparison equipment, the other is the phase comparison equipment. These two systems are available only when 120 Vac power is operating.

**1. Time comparison.** The accumulated clock error rate on the FTS clock should be  $4 \times 10^{-13} \Delta T/T$ , which is large enough to require frequent calibrations of the FTS clock. In order to have knowledge of time to microsec level, it is necessary to use some sort of high-precision time transfer. Several methods exist to accomplish this (Ref. 5). For the ORION FTS, the following four time transfer methods are being considered:

- (a) Traveling atomic clock.
- (b) Loran-C.
- (c) Transit or Nova satellite.
- (d) Global positioning satellite (NAVSTAR).

All four of these methods will be considered and a tradeoff study will be made. The method selected should be determined by June 1981. Some obvious considerations for this selection are listed below:

- (a) The cost of the traveling clock to maintain submicrosec clock accuracy.
- (b) The unavailability of Loran-C throughout the world (particularly the southern hemisphere).
- (c) The new and relatively untried aspects of satellites for time synchronization to submicrosec accuracy.
- (d) Ability to meet the system requirements for time synchronization.

This same accumulated clock error data will be used to determine the long-term ( $>10$  days) frequency stability of the hydrogen maser. This information will be used to help determine the need for maintenance.

**2. Phase comparison.** The purpose of the phase comparison system is to give immediate information on the output frequency of the hydrogen maser. Another frequency standard, a rubidium vapor unit, is needed so that the hydrogen maser can be compared to it. The 5-MHz signals from the rubidium unit and the hydrogen maser are compared in a phase comparator; the analog output is read and digitized by an analog-to-digital converter. The data are then sent to the mobile unit computer for analysis. This analysis can quickly detect any severe frequency offset between the two frequency standards, and also provide stability information on the rubidium.

There are two additional uses for the rubidium frequency standard. The rubidium frequency standard has a built-in digital clock, and with this backup clock FTS time to the microsec can be recovered in the event of the failure of the FTS clock. The rubidium standard could also be used as the FTS frequency standard in the event the hydrogen maser is unavailable (Ref. 6).

## V. Operation of the FTS

### A. Modes of Operations

**1. Operating mode.** This is when the mobile unit is on site and operating or preparing to operate. The ac power is being supplied, the van is air conditioned and the computer is operating.

**2. Transit mode.** This is when the mobile unit is being moved from one site to another; dc power is being supplied to only the hydrogen maser compartment. This powers the compartment air conditioner, hydrogen maser and necessary auxiliary equipment. The other subsystems are not operating.

**3. Withstanding mode.** This mode exists when the mobile unit subsystems cannot be supplied power. All of the equipment must be shut down. (A hydrogen maser must be shut down using a procedure specified by the manufacture. If the hydrogen maser is shut down it must be supplied high voltage pump power to prevent damage.) This is an undesirable situation but one which must be planned for. If the hydrogen maser is shut down it will require several weeks to restabilize it after it is restarted. It will take a considerable effort to reestablish the time of the FTS clock, which means, of course, that the four-hour requirement to operational status is no longer applicable.

### B. Operation

The ORION mobile unit personnel have a minimum number of tasks to perform. Some of the tasks that must be accomplished by the mobile unit personnel are listed below:

- (1) Erect the antenna for the time comparison system. This should be a several-minute operation and it should involve no connections or disconnections of cables.
- (2) Reconfigure the FTS. This would occur only if there were a failure in a major part of the FTS.
- (3) Reestablish FTS clock time. If time were lost on the FTS clock a time transfer would have to be made from the rubidium clock.
- (4) Setup time comparison system. All of the possible time comparison systems will use a time interval counter. This will have to be put into operation.

- (5) Evaluate the real-time monitor functions to verify performance.

## **VI. FTS Requirements of Other Subsystems**

### **A. Monitor and Control**

The following functions must be performed by the monitor and control subsystem:

- (1) A constant record of time offset between the FTS clock and the external clock needs to be kept. Furthermore, long-term records need to be kept to establish the performance of the frequency standard. "Long term" is meant to be several months to one or two years.
- (2) Operating data on the hydrogen maser consist of the many operating parameters provided by the hydrogen maser microprocessor. The data should be available when requested by the ORION mobile computer unit and should be included within the regular reporting procedures.
- (3) Phase offset data between the hydrogen maser and the rubidium frequency standard will be used to check on the immediate operation of the hydrogen maser and so must be available at the ORION mobile computer unit.

### **B. Power Requirements**

The FTS requires 28 Vdc power at approximately 9 A. This power is required continuously except when ac power is applied or when the mobile unit is in the withstanding mode.

During the operating mode, the FTS requires 120 Vac power at about 6 A.

### **C. Space Requirements**

The compartment that holds the hydrogen maser and the other continuously operated components of the FTS must be at least 170 cm wide, 220 cm long, and 225 cm tall. The remaining equipment in the FTS will fit in less than 150 cm of cabinet height.

### **D. Vibration Protection**

A vibration dampening device needs to be installed between the hydrogen maser and the mobile unit structure. This will protect the physics unit during transit of the mobile unit. Because the design of a vibration dampening device is so dependent on the weight mounting hole locations and center of gravity location of the hydrogen maser unit, it was decided to make it a part of the FTS.

### **E. Antennas**

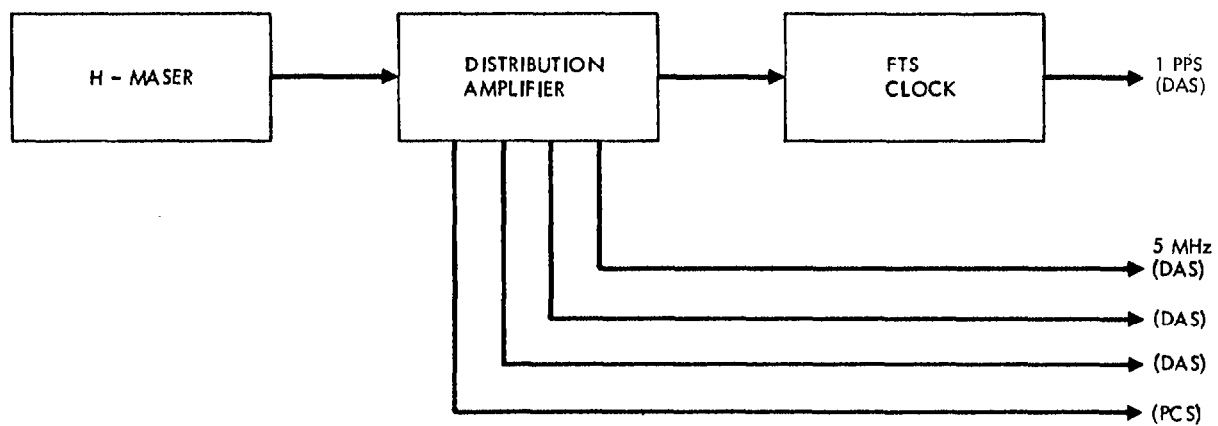
If the time comparison system uses an antenna, it will need to be mounted on top of the electronics van. The time comparison will need to have an unobstructed view of the sky, and yet it must not interfere with the movement of the van.

### **F. Temperature**

Perhaps the most critical requirement to achieve the stability performance of the FTS is that ambient temperature surrounding the hydrogen maser must be stable to 0.1°C during operation and for 48 hours prior to operation.

## References

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**Fig. 1. The basic frequency and timing system**

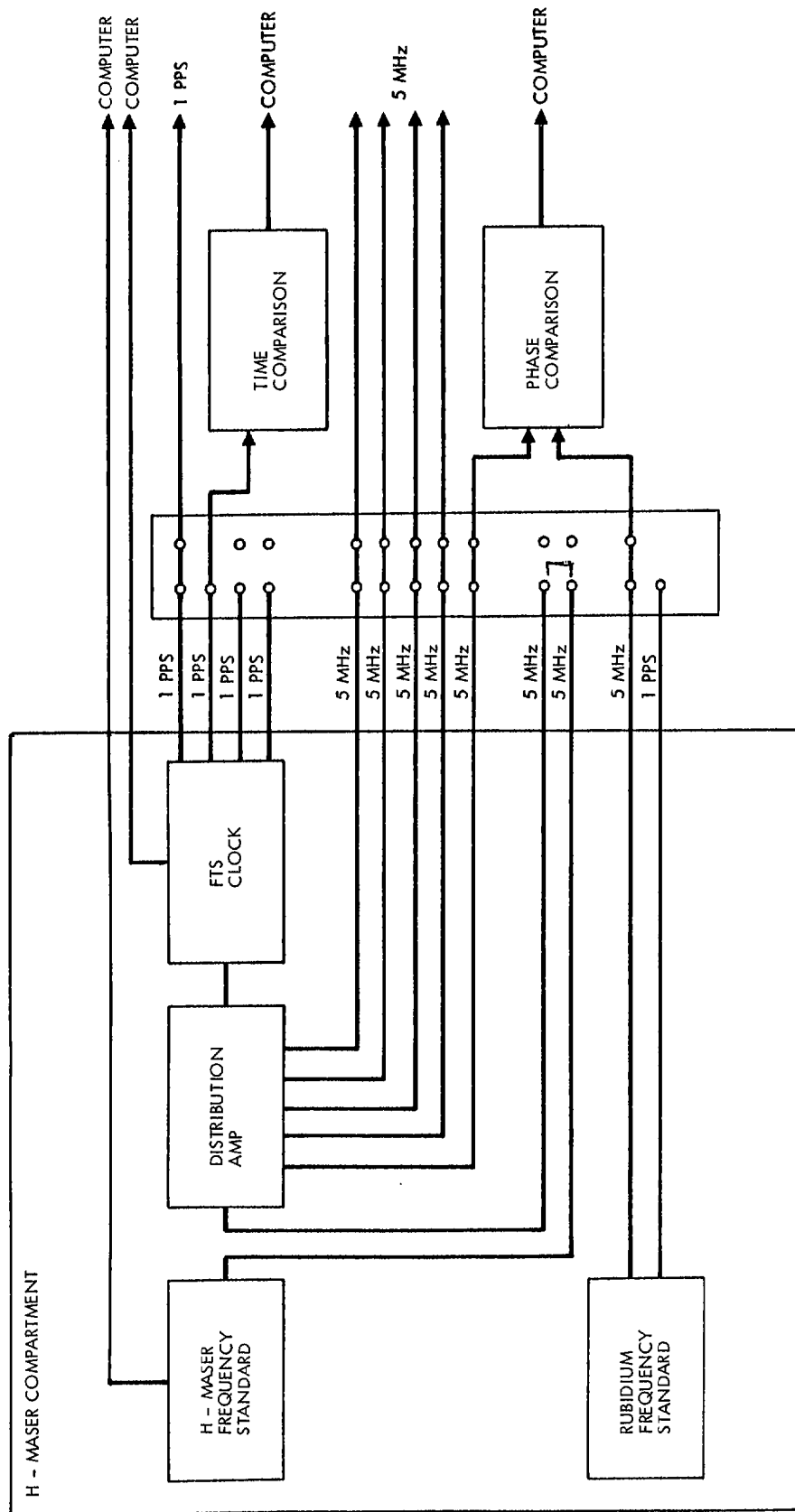


Fig. 2. The complete frequency and timing system